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EFFECT OF REST PERIODS ON FATIGUE OF HIGH-PURITY ALUMINUM

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California Institute of Technology

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SUMMARY

The effect of rest periods on the fatigue life of high-purity aluminum was investigated under two conditions. In one the specimens were tested at elevated temperatures and the rest periods were given at room temperature; in the second the specimens were tested at room temperature and the rest periods were given at elevated temperature. The results obtained indicated that the increase of life was negligible in the first condition, but an increase of life may be obtained in the second. In order to check this increase in fatigue life a second series of tests has been carried out on a different lot of specimens and again an increase in life was found. This increase of life appeared to be from 30 to 60 percent from the average of the results of 20 tests for each test condition.

INTRODUCTION

While a considerable amount of work has been done in the general field of the fatigue of metals, relatively little attention was paid to the effect of rest periods on fatigue. This work was briefly summarized by Cazaud (ref. 1) and discussed in some detail by Freudenthal, Yen, and Sinclair (ref. 2). The discussion in reference 2 was primarily centered around a theory developed by Freudenthal and Dolan (ref. 3) in which it was imagined that the fatigue failure was determined by the interplay between what they term "bond disruption," "bond relaxation," and "creation of potential damage nuclei." They argue that where intermittent rest periods contribute to an increase in fatigue life it is a consequence of bond relaxation leading to a removal of the nuclei for potential damage obtained during the prior fatigue stress history. Their analysis concludes that rest periods may contribute to an increase in fatigue life if the resting temperature is within the range of recovery temperature. Their experiments show that although rest periods do give rise to an increase in fatigue life for SAE 4340 and SAE 1045 steels they reduced the fatigue life of electrolytic copper. Sinclair and Dolan conducted some tests on cartridge brass (ref. 4) and they came to the conclusion that rest periods at 1/5-life intervals have no effect on fatigue life.

It now seems to be accepted that the fatigue failure in high-purity metals is preceded by accelerated recrystallization at temperatures substantially lower than the normal recrystallization temperatures. For example, it is established that, whereas this recrystallization temperature is around 300° F and up for aluminum, polygonization followed by growth of subgrains was observed at room temperatures (72° F) for high-purity aluminum. In the case of precipitation-hardening alloys, it was found that fatigue-stressing accelerates the precipitation process leaving regions depleted of solute atoms, regions in which again recrystallization may take place (ref. 5). Thus it appears that, while in principle a rest period may contribute to an increase in fatigue life if the resting temperature is not near the recrystallization temperature, in the case of precipitation-hardening alloys of aluminum this probable increase may easily be changed by the adverse effect of the precipitation process involved in the process of testing the material and also probably involved in resting at elevated temperatures. For a fully hardened alloy, it is conceivable that the process of resting at elevated temperatures may lead to an overaging of the test material and in fact may even give rise to a decrease in life instead of an increase. It was therefore felt that what is needed is information on high-purity aluminum under controlled conditions rather than on an aluminum alloy. It was felt that if an effect of rest periods exists it should become apparent in such a testing.

The work of the present report also was prompted by an observation made earlier (ref. 6) that, during a period of rest following a period of fatigue, substantial changes in the internal friction of commercially pure aluminum could be noticed. Since rest periods at elevated temperatures contribute to a rearrangement of internal stresses, the effect of rest on fatigue life appeared to be a pertinent problem for investigation. In order to accumulate data that would be sufficiently simple to analyze at a later date, high-purity aluminum was chosen for investigation. The work was conducted at the Guggenheim Aeronautical Laboratory of the California Institute of Technology under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. It is with pleasure that the authors acknowledge the helpful suggestions of Prof. Sechler.

SYMBOLS

N	number of cycles to failure
S	stress, psi
σ	standard deviation
$(\bar{\ })$	average

MATERIAL AND SPECIMENS

The test material used in this investigation was high-purity aluminum supplied by the Aluminum Co. of America. The material used in the first series of tests had the following composition (as reported by the manufacturer): Aluminum, 99.996 percent; zinc, 0.003 percent; and silicon, 0.001 percent. The material used in the second series of tests had the following composition: Aluminum, 99.993 percent; zinc, 0.004 percent; copper, 0.001 percent; silicon, 0.001 percent; and iron, 0.001 percent. The yield point and the ultimate strength in tension of the material as received were 6,750 psi at 0.2-percent-offset strain and 9,800 psi, respectively. The test material was supplied in the form of 1/2-inch-diameter rods 12 feet long and was described by the company as hand-forged. There was evidence of a considerable amount of preferred orientation of the grain along the length of the rod and it appears reasonable to assume that internal stresses due to cold work exist in the material as received. The recrystallization temperature as determined from hardness-against-temperature measurements was found to be 400° F.

Standard R. R. Moore test specimens with a minimum diameter of 0.30 inch were machined from the as-received test stock. The specimens were polished first with 240 emery paper and then with 600 grit paper with lard oil. This procedure provided an average surface finish of a 7-micron roughness. Lavigated alumina powder was tried for final polishing, but microscopic examination revealed this to be unsatisfactory.

TESTING MACHINES

The testing was conducted on eight rotary bending machines of the R. R. Moore type. All machines were designed for a nominal speed of 10,000 rpm but had been modified with rheostat control to operate at speeds as low as 2,000 rpm. Because of the high ductility of the test material, failure of the specimens seldom occurred as a clean break, but more as a relatively slow sagging, especially at higher temperatures. Since at high speeds this eccentricity was sufficient to cause violent vibrations of the bearing housings, the testing speed was restricted to 5,000 rpm.

The test specimens were enclosed in clam-shell-type furnaces, a detailed design of which was discussed in reference 7. The temperature variation spanwise was found to be from about 2.0 percent minimum at 150° F to 9 percent maximum at 450° F. Except during the transition period of heating and cooling, the timewise variation was ±1 percent.

PROCEDURE

Operation of the furnaces and R. R. Moore machines for continuous stress cycling of a specimen consisted simply of preheating the specimen in the machine to the desired temperature and applying the load. The proper powerstat and pyrometer settings would then maintain the test temperature without further attendance until failure occurred. When rest periods were given to the specimens a more rapid heating technique was desirable, and the testing procedure became more involved. For the sake of clarity, therefore, discussions of the various procedural aspects of the investigation are presented separately below.

The temperatures selected for the continuous-cycling phase of the investigation were: Room temperature (72° F), 150°, 300°, 450°, and 600° F. A stress level for these tests was chosen so that failure at room temperature would occur at about 2×10^6 cycles. The nominal outer fiber stress was 6,040 psi. This same stress level was used for specimens given periods of rest at room temperature from cycling at 150°, 300°, and 450° F. The resting times were given at intervals of 1/5 mean life, as determined from the continuous-cycling tests.

In another phase of the testing, the specimens were given rest periods at 150°, 300°, and 450° F after cycling at room temperature (72° F). So that an individual test could be carried to completion within a reasonable amount of time a stress level of 6,800 psi was used for this phase of the tests. The rest periods were again given at intervals of 1/5 mean life as determined from continuous cycling at the same stress level and at room temperature.

Since a different lot of material was used for the second series of tests, it was decided to run 20 continuous-cycling tests at the same stress level (6,800 psi) as for the first series. As will be seen, this lot of material has a higher fatigue strength for the same stress level than the first lot has. The rest periods for the second series of tests were given at 300° F at 1/4-mean-life intervals.

The rest period for resting at room temperature was arbitrarily defined to be of 30-minute duration, such a period to commence from the time the cooling specimen reached a temperature of about 100° F. For resting at elevated temperature, the periods were of similar duration with the timing started from the time the specimen reached the desired temperature. The rest periods so defined were, therefore, exclusive of the heating and cooling times required.

Calibrations for determining the settings were accomplished by placing a thermocouple under the head of a screw at the center of the specimen. The powerstat and pyrometer settings were then adjusted until the desired specimen temperature was attained. Because of space limitations it was not considered feasible to install slip rings and conduct dynamic calibrations. Times to attain and stabilize at the various temperatures were determined during calibration. These times were lessened if the bearings and furnace had been previously heated. From a cold start the time to stabilize at 600° F was about 1 hour, with the times to other test temperatures being less.

Static calibrations for determining the heating and cooling times for intermittent rest periods were carried through several cycles of heating and cooling in order to simulate actual testing of the specimens. Cooling was accomplished with small electric blower fans. As given below, the average times required were:

Temperature, °F	150	300	450	600
Heating time to temperature, min	3	5	8	12
Cooling time from temperature to 100° F, min . .	2	9	13	15

Figure 1 shows schematically the rest-period cycle indicated above. The technique for continuous cycling was to start the specimen in the machine, bring it up to temperature, and apply the load. With the proper pyrometer and powerstat settings the specimen was maintained at the correct temperature.

When giving rest periods, a more rapid means of bringing the specimen up to temperature was desired. Toward this end the pyrometers were used simply as indicators of the furnace temperatures. This was done by setting the pyrometer selector beyond the range of the expected furnace temperature so that the current to the furnace would never be interrupted. Excessive power was then introduced to the furnace by adjusting the powerstat until the specimen reached the desired temperature. This temperature was then maintained by gradually reducing the power input until a stable setting was reached. Graphs of pyrometer readings versus time were constructed, and these curves were used whenever a particular temperature was to be obtained. This procedure not only gave considerably decreased warmup times but also had the advantage that closer control of specimen temperature was possible. It also reduced some of the doubt as to the validity of static calibrations, since, with the machines running, practically identical furnace temperatures were obtained with the same power-input-versus-time sequence.

In order to avoid unnecessary vibrations once a test was begun, the machines were never stopped unless trouble developed. The load was simply removed or applied at the proper times, and the rest periods given until failure occurred. Transient vibrations during starting were best controlled by constraining the counterweights on the bearing housings and starting the machines at their nominal speed of 10,000 rpm. The speed was then adjusted to 5,000 rpm. All specimens that developed a visible transient vibration were discarded.

RESULTS

The results of the fatigue tests are contained in tables I and II. These tables give, for the different test phases, the number of cycles which the individual specimens sustained before failure. The computed values of the standard deviations and the means $\overline{N}$ and $\overline{\log N}$ for the 99- and 95-percent levels of confidence have been entered on the tables. A compilation of these values is given by table III. After having been statistically evaluated, the data are presented in the form of frequency distributions (histograms) of $\log N$ in figures 2 to 6. For comparison, the Gaussian distribution is superimposed on each histogram.

Assuming the data to be logarithmic-normal (ref. 8), continuous frequency distributions of $\log N$ derived from results of the uninterrupted tests at room temperature for $S = 6{,}040$ psi and $S = 6{,}800$ psi have been used to draw a statistically interpretable diagram of S against $\log N$ for the material. The diagram is shown in figure 7. Data of incidental tests at various other stress levels are indicated on the diagram by points. Under the same assumption of the data being logarithmic-normal, the diagram of temperature against $\log N$ in figure 8 was constructed.

In fatigue-testing, one can probably never accumulate enough data. An average of 18 specimens was tested in each phase, in the hope that at least the trends might be adequately uncovered. As far as possible all specimens of one series were tested with the same machine and furnace. When this was not done, the results were scrutinized for any variations between machines. On the basis of the results obtained, no deviations were detected. The average number of cycles to failure at the various temperatures for continuous cycling are given below:

Temperature, $^{\circ}$F	72	150	300	450	600
$\overline{N} \times 10^{-6}$ cycles for 6,040 psi . .	2.537	0.868	0.414	0.173	0.114

The continuous-cycling results also indicate a minimum of scatter at 300° F, as shown in figure 8.

For specimens rested at 300° F, the data show an average fatigue life of 1.041×10^6 cycles compared with a life of 0.663×10^6 cycles under continuous-stress cycling at room temperature (an increase of 57 percent). When rest periods at 150° F were given, the mean life was 0.919×10^6 cycles, an increase of 39 percent. For resting at 450° F, 0.826×10^6 cycles was the mean life, showing an increase of 25 percent. For the second series run with rest periods at 1/4-life intervals, the same trend was repeated with an increase in the average fatigue life of 35 percent. These results calculated for 95- and 99-percent confidence levels are given in table III. For the 95-percent confidence level, the increase in fatigue life when the specimen was rested at 300° F was found to be 3 percent for the first series of tests and for the second lot it was found to be 11 percent. The corresponding values for the 99-percent confidence level were a decrease of 14 percent and an increase of 2 percent, respectively.

CONCLUSIONS

The following conclusions were drawn from the results of the present investigation of the effects of rest periods on the fatigue life of high-purity aluminum:

1. Resting at room temperature (72° F) after stressing at elevated temperatures up to 450° F has no effect on the fatigue life of high-purity aluminum.

2. An increase in fatigue life may be obtained by resting at elevated temperatures after stressing at room temperature. It appears that the maximum benefit is obtained by giving the rest period at a temperature somewhat below the recrystallization temperature. In the present investigation where the recrystallization temperature was 400° F, the maximum benefit was obtained with a rest period at 300° F.

California Institute of Technology,
Pasadena, Calif., August 1, 1956.

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TABLE I

S-N DATA AT 72° F

Specimen	Applied load, lb	Stress, S	Number of cycles to failure, N	log N
1	10.5	7,930	192×10^3	5.283
2	10.2	7,700	330	5.619
3	10.0	7,550	363	5.560
4	9.5	7,170	619	5.792
5	9.0	6,800	985	5.993
6	8.5	6,420	1,120	6.049
7	8.0	6,040	1,511	6.179
8	7.8	5,890	1,746	6.242
9	7.7	5,810	4,014	6.604
10	7.5	5,660	3,950	6.597
11	7.0	5,280	6,958	6.842
12	6.0	4,530	[a]18,675	7.271
13	5.0	3,775	[a]47,437	7.676
14	2.0	1,510	[a]54,069	7.733

[a]Test discontinued.

TABLE II

NUMBER OF CYCLES TO FAILURE

(a) S = 6,040 psi; all first-series tests

Continuous cycling; stressed at - 72° F

Specimen	N	log N
1	1,150 × 10^3	6.061
2	1,208	6.082
3	1,334	6.125
4	1,403	6.147
5	1,504	6.177
6	1,511	6.179
7	1,552	6.191
8	1,631	6.212
9	1,714	6.234
10	1,844	6.266
11	1,940	6.288
12	2,795	6.446
13	2,894	6.461
14	2,989	6.476
15	3,058	6.485
16	3,059	6.486
17	3,186	6.503
18	3,406	6.532
19	3,657	6.563
20	3,666	6.564
21	4,021	6.604
22	6,291	6.799

$\bar{N}$ = 2,537,000 cycles
σ of N = 1,220,000 cycles
$\overline{\log N}$ = 6.358
σ of log N = 0.198
$\bar{N}$ at 99-percent level of confidence = 2,537,000 ± 755,000 cycles
$\bar{N}$ at 95-percent level of confidence = 2,537,000 ± 550,000 cycles

Continuous cycling; stressed at - 150° F

Specimen	N	log N
1	259 × 10^3	5.413
2	357	5.553
3	370	5.568
4	505	5.703
5	507	5.705
6	569	5.755
7	602	5.780
8	603	5.780
9	651	5.814
10	660	5.820
11	663	5.822
12	687	5.837
13	754	5.877
14	777	5.890
15	798	5.902
16	809	5.908
17	836	5.922
18	855	5.932
19	862	5.936
20	870	5.940
21	912	5.960
22	942	5.974
23	1,000	6.000
24	1,096	6.040
25	1,122	6.050
26	1,172	6.069
27	1,217	6.085
28	1,237	6.092
29	1,280	6.107
30	1,382	6.141
31	1,633	6.213
32	1,807	6.257

$\bar{N}$ = 868,000 cycles
σ of N = 352,000 cycles
$\overline{\log N}$ = 5.901
σ of log N = 0.186
$\bar{N}$ at 99-percent level of confidence = 868,000 ± 169,000 cycles
$\bar{N}$ at 95-percent level of confidence = 868,000 ± 108,000 cycles

Continuous cycling; stressed at - 300° F

Specimen	N	log N
1	268 × 10^3	5.428
2	301	5.479
3	306	5.486
4	337	5.528
5	352	5.547
6	353	5.548
7	416	5.619
8	433	5.636
9	435	5.638
10	468	5.670
11	478	5.679
12	485	5.686
13	494	5.694
14	497	5.696
15	584	5.766

$\bar{N}$ = 414,000 cycles
σ of N = 87,300 cycles
$\overline{\log N}$ = 5.607
σ of log N = 0.095
$\bar{N}$ at 99-percent level of confidence = 414,000 ± 69,000 cycles
$\bar{N}$ at 95-percent level of confidence = 414,000 ± 50,000 cycles

Continuous cycling; stressed at - 450° F

Specimen	N	log N
1	98 × 10^3	4.991
2	99	4.996
3	118	5.072
4	128	5.107
5	147	5.167
6	152	5.182
7	157	5.196
8	167	5.223
9	176	5.246
10	187	5.272
11	197	5.294
12	204	5.310
13	205	5.312
14	205	5.312
15	207	5.316
16	215	5.332
17	222	5.346
18	224	5.350

$\bar{N}$ = 173,000 cycles
σ of N = 40,400 cycles
$\overline{\log N}$ = 5.224
σ of log N = 0.113
$\bar{N}$ at 99-percent level of confidence = 173,000 ± 28,000 cycles
$\bar{N}$ at 95-percent level of confidence = 173,000 ± 20,000 cycles

Continuous cycling; stressed at - 600° F

Specimen	N	log N
1	39 × 10^3	4.591
2	54	4.732
3	90	4.954
4	90	4.954
5	94	4.973
6	96	4.982
7	101	5.004
8	133	5.124
9	159	5.201
10	161	5.207
11	166	5.220
12	189	5.276

$\bar{N}$ = 114,000 cycles
σ of N = 45,000 cycles
$\overline{\log N}$ = 5.018
σ of log N = 0.196
$\bar{N}$ at 99-percent level of confidence = 114,000 ± 42,000 cycles
$\bar{N}$ at 95-percent level of confidence = 114,000 ± 30,000 cycles

Rested at 72° F; stressed at - 150° F

Specimen	N	log N
1	526 × 10^3	5.721
2	569	5.755
3	605	5.782
4	889	5.949
5	952	5.979
6	1,029	6.012
7	1,035	6.015
8	1,083	6.035
9	1,086	6.036
10	1,136	6.055
11	1,157	6.063
12	1,230	6.090
13	1,271	6.104
14	1,291	6.111
15	1,343	6.128

$\bar{N}$ = 1,013,000 cycles
σ of N = 254,000 cycles
$\overline{\log N}$ = 5.989
σ of log N = 0.128
$\bar{N}$ at 99-percent level of confidence = 1,013,000 ± 202,000 cycles
$\bar{N}$ at 95-percent level of confidence = 1,013,000 ± 148,000 cycles

Rested at 72° F; stressed at - 300° F

Specimen	N	log N
1	148 × 10^3	5.170
2	244	5.387
3	266	5.425
4	275	5.439
5	322	5.508
6	322	5.508
7	345	5.538
8	348	5.542
9	377	5.576
10	401	5.603
11	557	5.764
12	558	5.747
13	563	5.751
14	590	5.771
15	804	5.905

$\bar{N}$ = 408,000 cycles
σ of N = 166,000 cycles
$\overline{\log N}$ = 5.574
σ of log N = 0.181
$\bar{N}$ at 99-percent level of confidence = 408,000 ± 132,000 cycles
$\bar{N}$ at 95-percent level of confidence = 408,000 ± 96,000 cycles

Rested at 72° F; stressed at - 450° F

Specimen	N	log N
1	112 × 10^3	5.049
2	118	5.072
3	135	5.130
4	138	5.140
5	142	5.152
6	147	5.167
7	149	5.173
8	173	5.238
9	173	5.238
10	196	5.292
11	203	5.307
12	208	5.318
13	237	5.375
14	244	5.387
15	255	5.407

$\bar{N}$ = 175,000 cycles
σ of N = 44,800 cycles
$\overline{\log N}$ = 5.230
σ of log N = 0.111
$\bar{N}$ at 99-percent level of confidence = 175,000 ± 36,000 cycles
$\bar{N}$ at 95-percent level of confidence = 175,000 ± 26,000 cycles

TABLE II.- Concluded

NUMBER OF CYCLES TO FAILURE

(b) S = 6,800 psi; first and second series of tests stressed at 72° F

First series of tests												Second series of tests					
Continuous cycling			Rested at 150° F			Rested at 300° F			Rested at 450° F			Continuous cycling			Rested at 300° F		
Specimen	N	log N	Specimen	N	log N	Specimen	N	log N	Specimen	N	log N	Specimen	N	log N	Specimen	N	log N
1	381×10^3	5.581	1	486×10^3	5.687	1	345×10^3	5.538	1	436×10^3	5.639	1	631×10^3	5.8	1	787×10^3	5.896
2	399	5.601	2	549	5.740	2	464	5.667	2	448	5.651	2	676	5.830	2	923	5.965
3	403	5.605	3	597	5.823	3	467	5.669	3	450	5.653	3	729	5.863	3	1,014	6.006
4	404	5.606	4	665	5.823	4	476	5.678	4	463	5.666	4	774	5.889	4	1,020	6.008
5	437	5.640	5	745	5.872	5	770	5.886	5	484	5.685	5	821	5.914	5	1,023	6.009
6	446	5.649	6	749	5.874	6	896	5.952	6	633	5.801	6	850	5.929	6	1,038	6.016
7	481	5.682	7	758	5.880	7	962	5.983	7	636	5.803	7	870	5.939	7	1,066	6.028
8	491	5.691	8	854	5.931	8	1,026	6.011	8	651	5.814	8	872	5.940	8	1,072	6.030
9	577	5.761	9	974	5.989	9	1,050	6.021	9	695	5.842	9	879	5.944	9	1,135	6.055
10	613	5.787	10	977	5.990	10	1,064	6.027	10	733	5.866	10	892	5.950	10	1,146	6.059
11	619	5.792	11	999	6.000	11	1,111	6.046	11	872	5.940	11	961	5.982	11	1,168	6.067
12	646	5.810	12	1,129	6.053	12	1,179	6.072	12	910	5.959	12	1,002	6.001	12	1,248	6.096
13	676	5.830	13	1,303	6.115	13	1,405	6.148	13	954	5.980	13	1,017	6.007	13	1,259	6.100
14	714	5.854	14	1,416	6.151	14	1,785	6.252	14	984	5.993	14	1,026	6.011	14	1,407	6.148
15	780	5.892	15	1,580	6.199	15	1,821	6.260	15	1,048	6.020	15	1,031	6.013	15	1,407	6.148
16	788	5.897				16	1,836	6.264	16	1,192	6.076	16	1,041	6.019	16	1,458	6.164
17	877	5.943							17	2,447	6.389	17	1,048	6.020	17	1,517	6.181
18	927	5.967										18	1,056	6.024	18	1,561	6.193
19	943	5.975										19	1,131	6.053	19	1,854	6.268
20	970	5.987										20	1,305	6.115	20	2,056	6.313
21	985	5.993															
22	1,025	6.011															

First series, continuous cycling:
$\bar{N}$ = 663,000 cycles
σ of N = 214,000 cycles
$\overline{\log N}$ = 5.798
σ of log N = 0.144
$\bar{N}$ at 99-percent level of confidence = 663,000 ± 132,000 cycles
$\bar{N}$ at 95-percent level of confidence = 663,000 ± 96,000 cycles

First series, rested at 150° F:
$\bar{N}$ = 919,000 cycles
σ of N = 313,000 cycles
$\overline{\log N}$ = 5.939
σ of log N = 0.146
$\bar{N}$ at 99-percent level of confidence = 919,000 ± 250,000 cycles
$\bar{N}$ at 95-percent level of confidence = 919,000 ± 181,000 cycles

First series, rested at 300° F:
$\bar{N}$ = 1,041,000 cycles
σ of N = 472,000 cycles
$\overline{\log N}$ = 5.976
σ of log N = 0.219
$\bar{N}$ at 99-percent level of confidence = 1,041,000 ± 359,000 cycles
$\bar{N}$ at 95-percent level of confidence = 1,041,000 ± 260,000 cycles

First series, rested at 450° F:
$\bar{N}$ = 826,000 cycles
σ of N = 465,000 cycles
$\overline{\log N}$ = 5.869
σ of log N = 0.189
$\bar{N}$ at 99-percent level of confidence = 826,000 ± 340,000 cycles
$\bar{N}$ at 95-percent level of confidence = 826,000 ± 246,000 cycles

Second series, continuous cycling:
$\bar{N}$ = 930,000 cycles
σ of N = 159,000 cycles
$\overline{\log N}$ = 5.962
σ of log N = 0.0757
$\bar{N}$ at 99-percent level of confidence = 930,000 ± 104,000 cycles
$\bar{N}$ at 95-percent level of confidence = 930,000 ± 76,000 cycles

Second series, rested at 300° F:
$\bar{N}$ = 1,258,000 cycles
σ of N = 308,000 cycles
$\overline{\log N}$ = 6.087
σ of log N = 0.100
$\bar{N}$ at 99-percent level of confidence = 1,258,000 ± 202,000 cycles
$\bar{N}$ at 95-percent level of confidence = 1,258,000 ± 147,000 cycles

TABLE III

COMPILATION OF STANDARD DEVIATIONS AND MEANS

Stress history	Number of specimens	$\overline{N}$	σ of $\overline{N}$	$\overline{N}$ at 95-percent confidence level	$\overline{N}$ at 99-percent confidence level	$\overline{\log N}$	σ of $\overline{\log N}$	$\overline{\log N}$ at 95-percent confidence level	$\overline{\log N}$ at 99-percent confidence level
First series of tests									
Continuous cycling at 72° F; S = 6,040 psi	22	2.537×10^6	1.220×10^6	[a]3.087×10^6	[a]3.292×10^6	6.358	0.198	[a]6.447	[a]6.481
Continuous cycling at 150° F; S = 6,040 psi	32	.868	.352	[a].976	[a]1.037	5.901	.186	[a]5.958	[a]5.990
Continuous cycling at 300° F; S = 6,040 psi	15	.414	.087	[a].464	[a].483	5.607	.095	[a]5.662	[a]5.683
Continuous cycling at 450° F; S = 6,040 psi	18	.173	.040	[a].193	[a].201	5.224	.113	[a]5.282	[a]5.303
Continuous cycling at 600° F; S = 6,040 psi	12	.114	.045	[a].144	[a].156	5.018	.196	[a]5.148	[a]5.202
Stressed at 150° F; rested at 72° F; S = 6,040 psi	15	1.013	.254	[b].865	[b].811	5.989	.128	[b]5.915	[b]5.887
Stressed at 300° F; rested at 72° F; S = 6,040 psi	15	.408	.166	[b].312	[b].276	5.574	.181	[b]5.469	[b]5.430
Stressed at 450° F; rested at 72° F; S = 6,040 psi	15	.175	.045	[b].149	[b].139	5.230	.111	[b]5.166	[b]5.141
Continuous cycling at 72° F; S = 6,800 psi	22	.663	.214	[a].759	[a].795	5.798	.144	[a]5.863	[a]5.887
Stressed at 72° F; rested at 150° F; S = 6,800 psi	15	.919	.313	[b].738	[b].669	5.939	.146	5.854	[b]5.823
Stressed at 72° F; rested at 300° F; S = 6,800 psi	16	1.041	.472	[b].781	[b].682	5.967	.219	[b]5.847	[b]5.800
Stressed at 72° F; rested at 450° F; S = 6,800 psi	17	.826	.465	[b].580	[b].486	5.869	.189	[b]5.769	[b]5.731
Second series of tests									
Continuous cycling at 80° F; S = 6,800 psi	20	0.930×10^6	0.159×10^6	[a]1.006×10^6	[a]1.034×10^6	5.962	0.0757	[a]5.998	[a]6.012
Stressed at 80° F; rested at 300° F; S = 6,800 psi	20	1.258	.308	[b]1.111	[b]1.056	6.087	.100	[b]6.04	[b]6.022

[a]Maximum value.
[b]Minimum value.

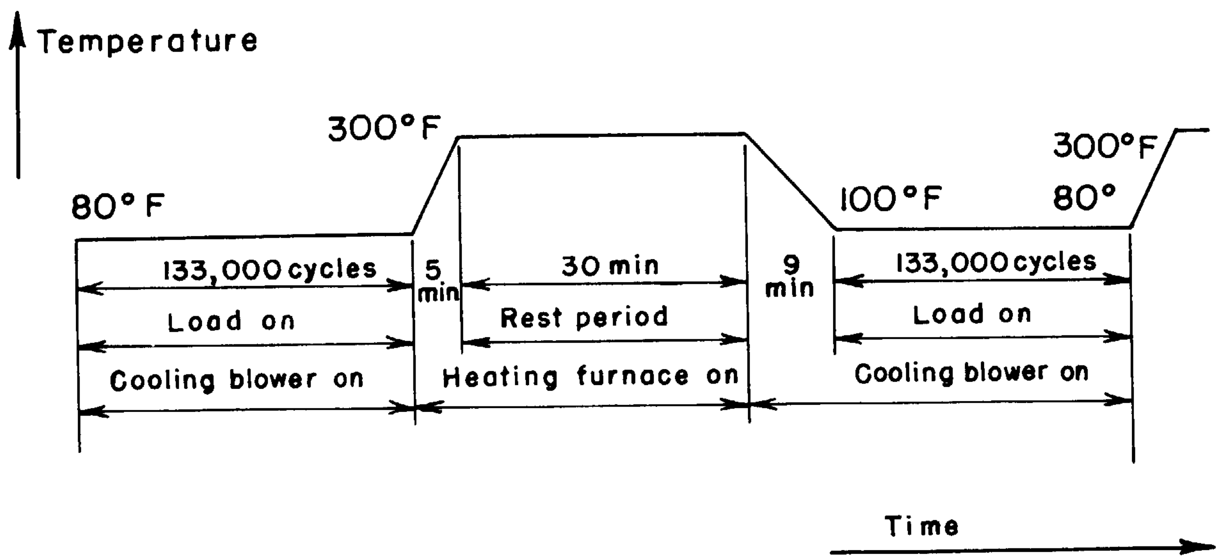

Figure 1.- Rest-period procedure. Example has 6,800-psi stress, continuous-cycling at room temperature, and rest periods at 300° F.

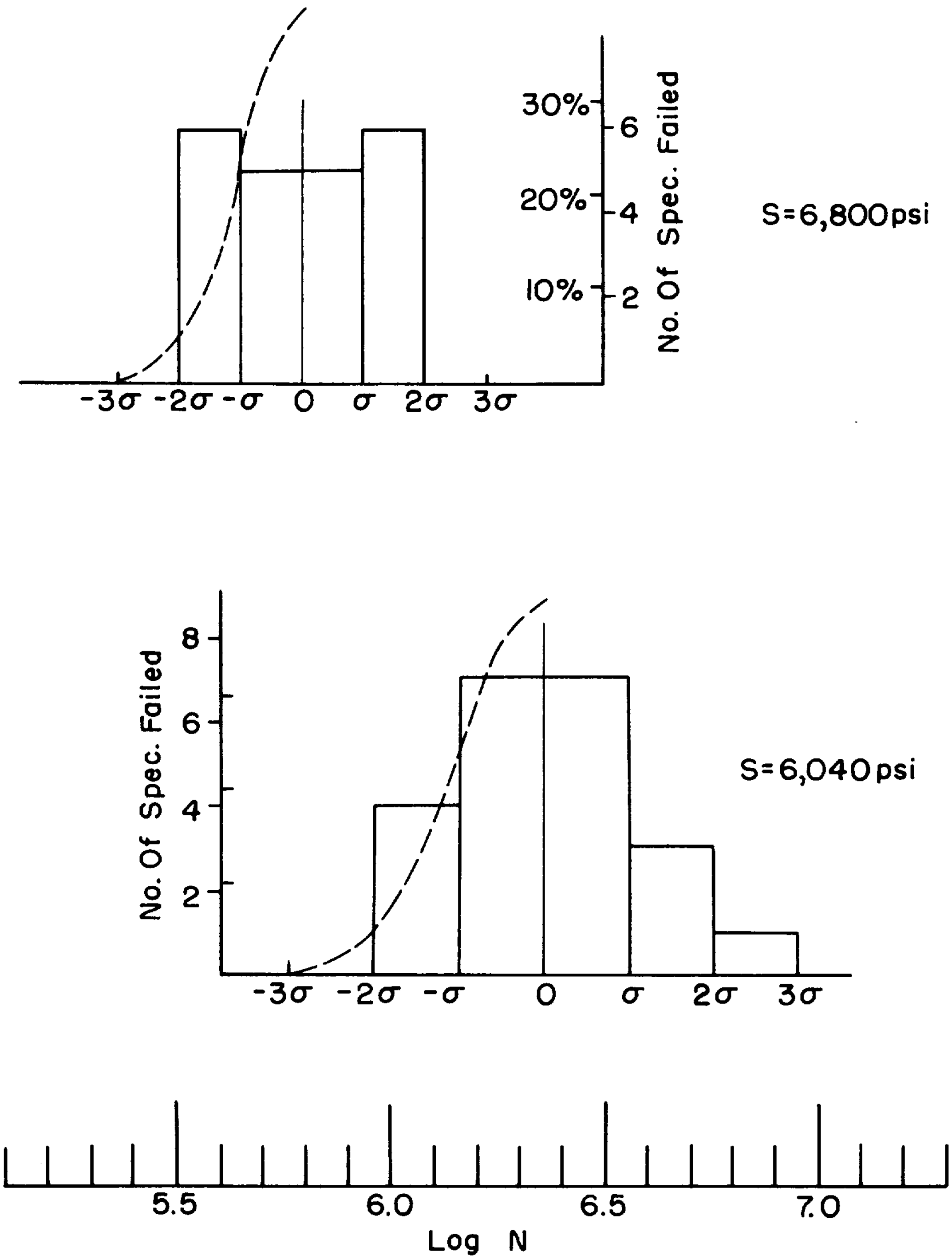

Figure 2.- Comparison of fatigure life under continuous cycling at room temperature.

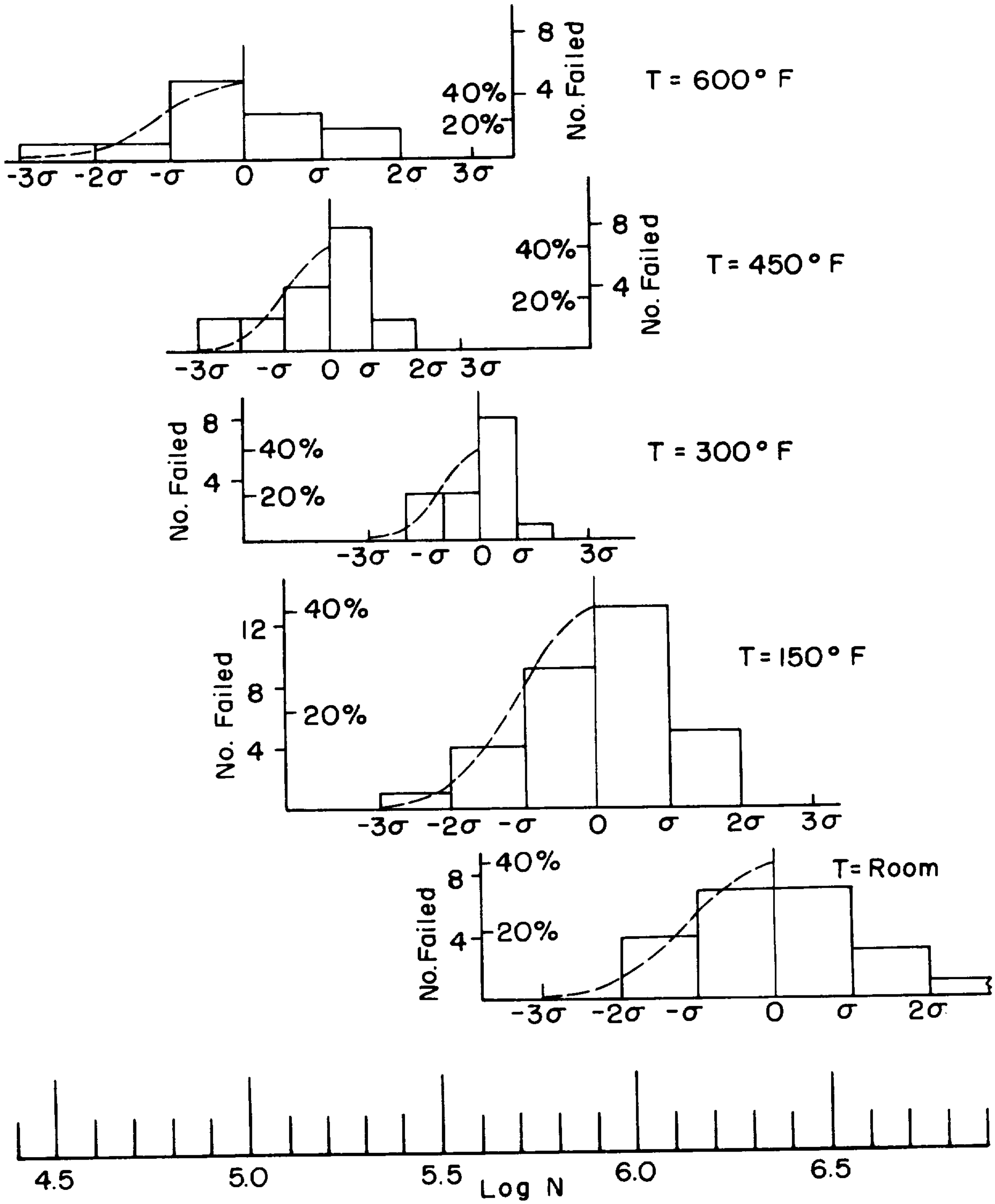

Figure 3.- Comparison of fatigue life under continuous cycling at S = 6,040 psi.

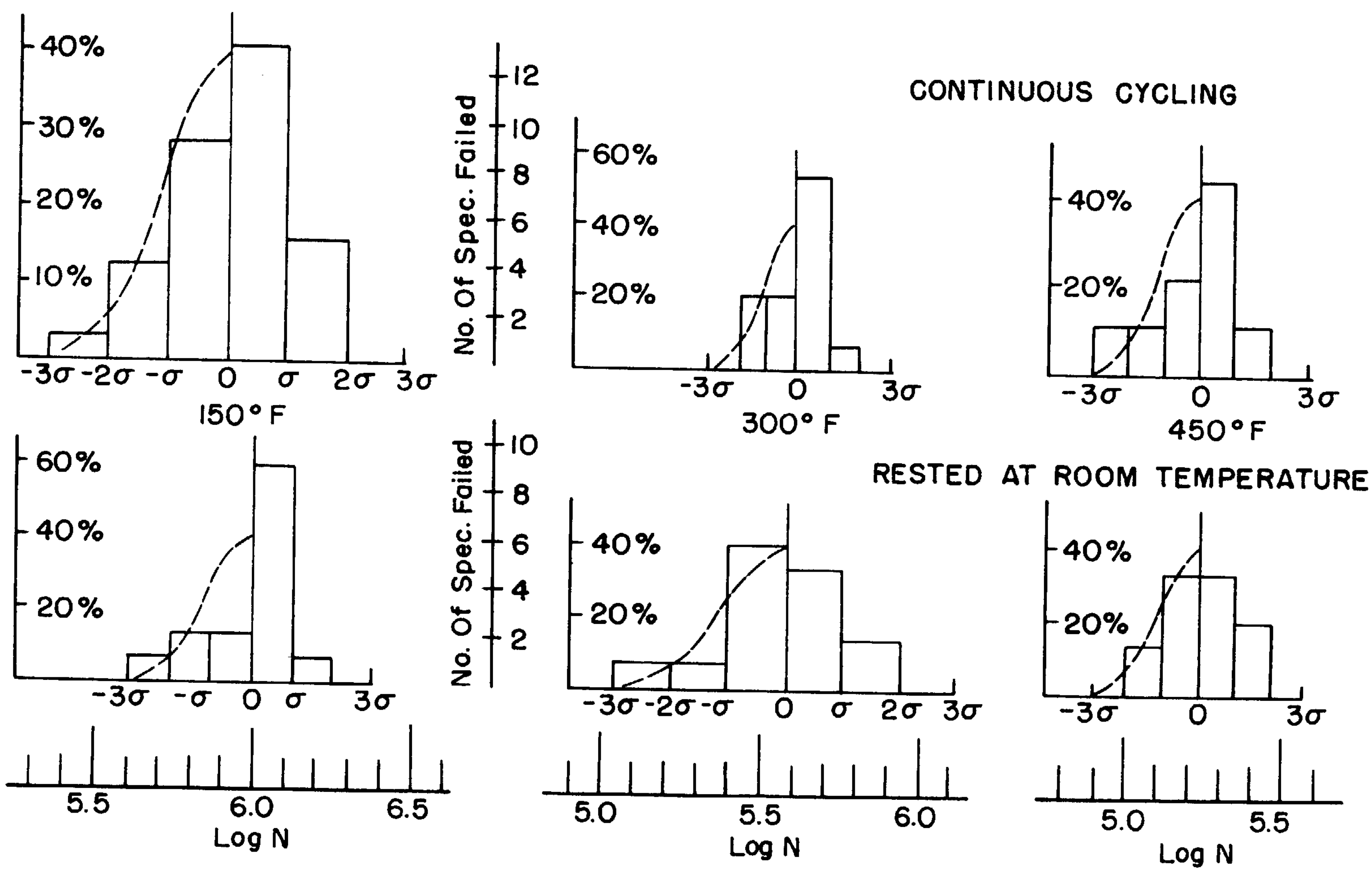

Figure 4.- Comparisons of fatigue life under cycling at 150°, 300°, and 450° F with rest periods at room temperature with fatigue life under continuous cycling at 150°, 300°, and 450° F. S = 6,040 psi.

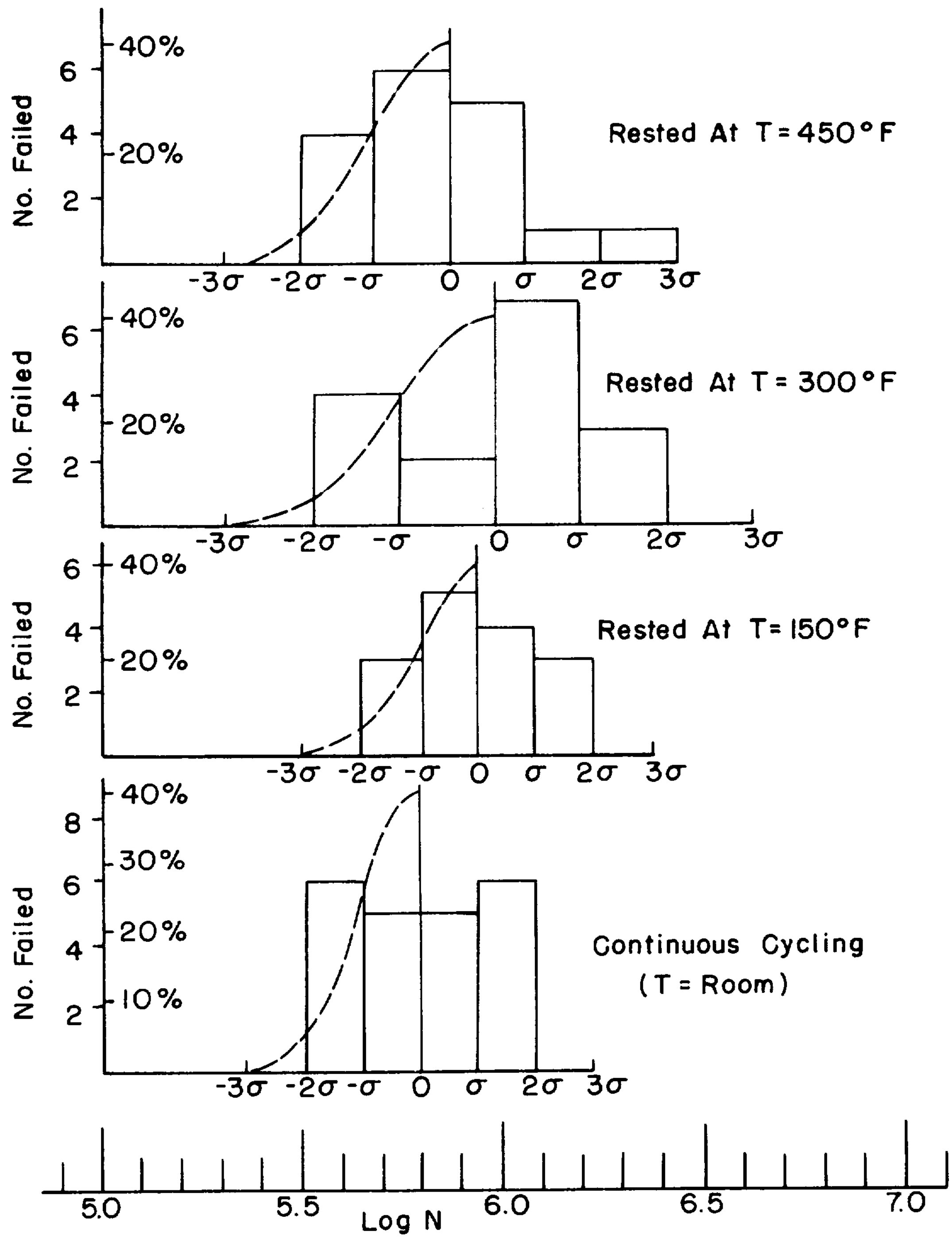

Figure 5.- Comparisons of fatigue life under cycling at room temperature with rest periods at 150°, 300°, and 450° F with fatigue life under continuous cycling at room temperature. S = 6,800 psi.

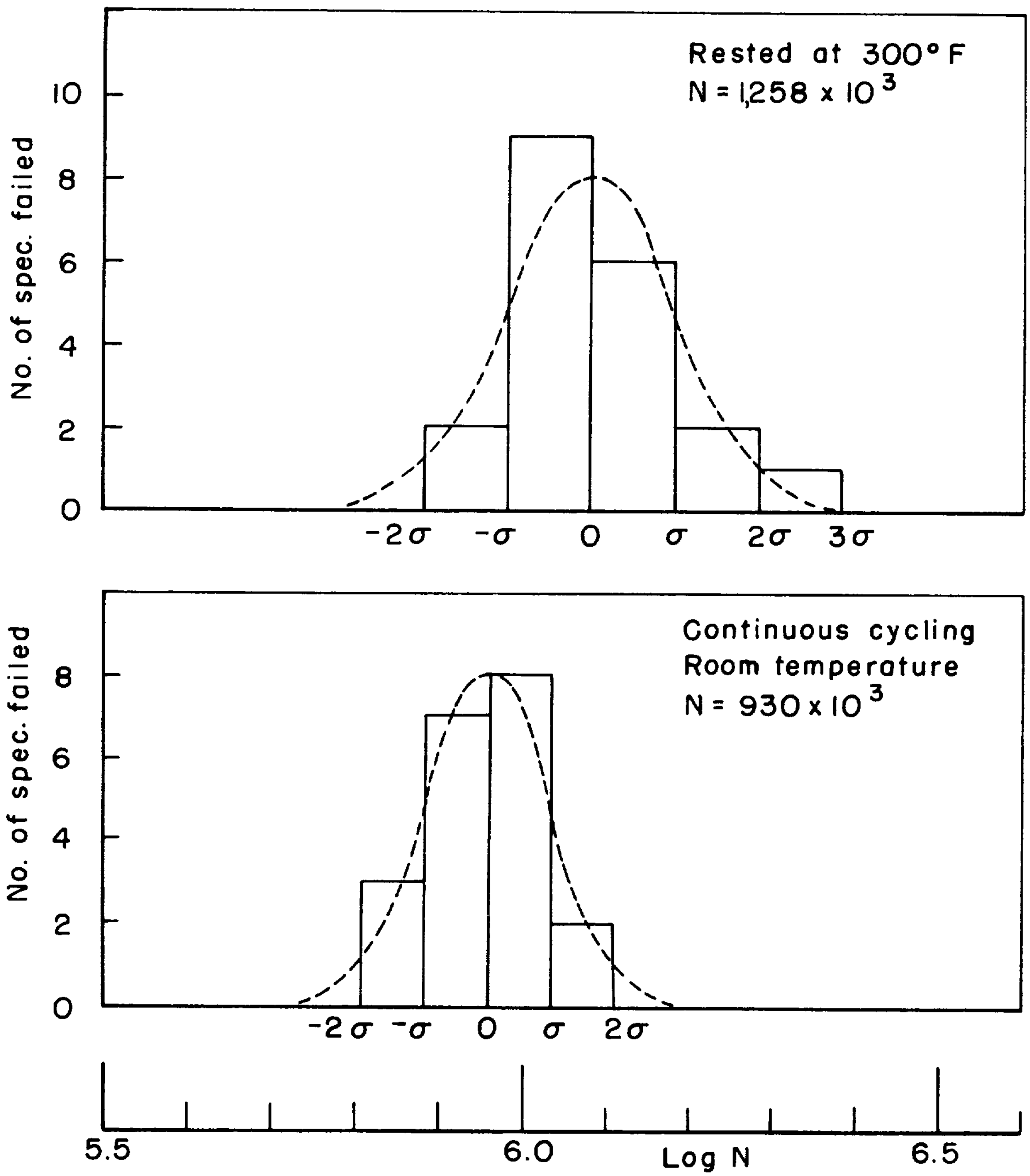

Figure 6.- Comparison of fatigue life under cycling at room temperature with rest periods at 300° F with fatigue life under continuous cycling at room temperature. Second series of tests; S = 6,800 psi.

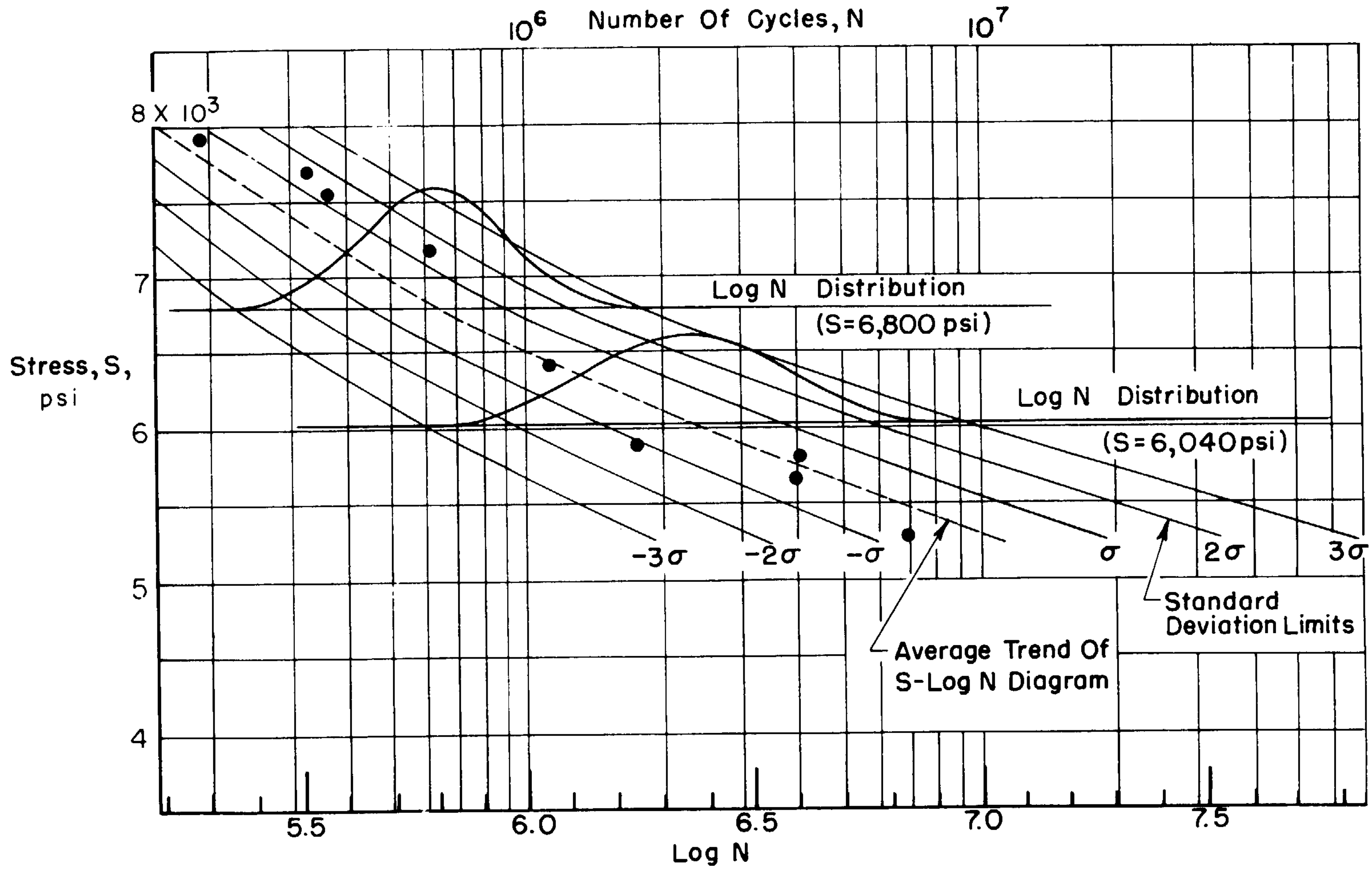

Figure 7.- Diagram of stress against log N for continuous cycling at room temperature.

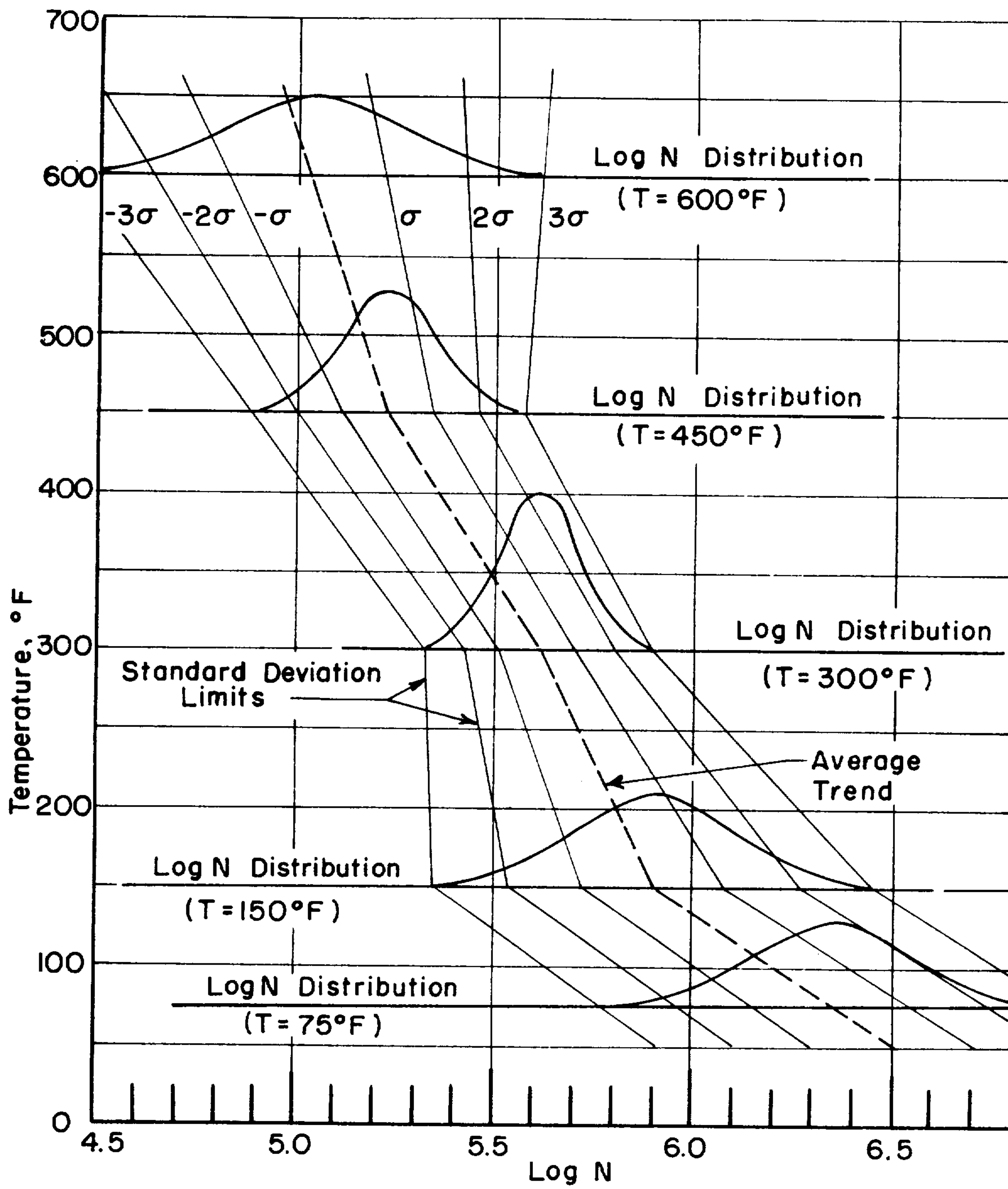

Figure 8.- Diagram of temperature against log N for continuous cycling at S = 6,040 psi.

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National Aeronautics and Space Administration.
EFFECT OF REST PERIODS ON FATIGUE OF HIGH-PURITY ALUMINUM. J. W. Berry, J. Lemaitre, and S. R. Valluri, California Institute of Technology. December 1958. 20p. diagrs., tabs. (NASA MEMORANDUM 11-21-58W)

Tests on aluminum specimens were performed under two conditions. In one the specimens were tested at elevated temperatures and the rest periods were given at room temperature; in the second the specimens were tested at room temperature and the rest periods were given at elevated temperature. The results obtained indicated that the increase of life was negligible in the first condition but that an increase of life may be obtained in the second. In order to check this increase in fatigue life, a second series of tests was carried out on a different lot of specimens and again an increase in life was found. This increase of life appeared to be from 30 to 60 percent from the average of the results of 20 tests for each test condition.

Copies obtainable from NASA, Washington

1. Loads and Stresses, Structural - Repeated Dynamic (4.3.7.7.1)
2. Aluminum (5.1.1)
3. Materials, Properties - Fatigue (5.2.5)

I. Berry, J. W.
II. Lemaitre, J.
III. Valluri, S. R.
IV. NASA MEMO 11-21-58W
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